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Solar energy for all? Understanding the successes and shortfalls through a critical comparative assessment of Bangladesh, Brazil, India, Mozambique, Sri Lanka and South Africa

Ankit Kumar[a,b,*], Raihana Ferdous[a], Andrés Luque-Ayala[a], Cheryl McEwan[a], Marcus Power[a], Britta Turner[a], Harriet Bulkeley[a]

[a] Department of Geography, Durham University, United Kingdom
[b] School of Innovation Sciences, Eindhoven University of Technology, The Netherlands

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ABSTRACT

Lanterns, homes systems, hot water systems and micro-grids based on small-scale solar have become prominent ways to address the energy access challenge. As momentum grows for this form of energy transition this paper draws together research on small-scale solar in six different countries – Bangladesh, Brazil, India, Mozambique, Sri Lanka and South Africa – to argue for a need to understand how, when, and for whom solar provides energy access. It argues that an assemblage perspective can provide vital insights into the diversity and dynamism of energy access. The paper demonstrates that the diverse ways in which solar provides energy access is a function of the flexibility/fixity of the socio-technical assemblage and the de/centralisation of agency.

The central thesis of this paper is that energy access is fluid and ever changing and we need fluid, easily maintainable, locally modifiable 'assemblages' for providing such access. Using this perspective, we find three common features of solar energy access across our case studies. First, there are significant gaps between what solar projects are designed to achieve and what they deliver, which are highly contingent on the flexibility of their structure and the decentralisation of agency within them. Second, access needs to endure continuously. Third, to foster enduring access, projects should embed logics of improvisation.

This paper is based on six separate qualitative research projects conducted during 2010–2016. It draws data from 482 interviews, 91 home tours and 12 group discussions.

1. Introduction

Providing access to "affordable, reliable, sustainable and modern energy for all" is regarded as central to development and enshrined as one of the Sustainable Development Goals ([1]:9 [2];). Yet what constitutes 'access' to energy remains a contested issue, with different approaches stressing different aspects, forms and beneficiaries of energy services as of central importance [3]. The UN Secretary-General's Advisory Group on Energy and Climate Change defines energy access as "access to clean, reliable and affordable energy services for cooking and heating, lighting, communications and productive uses" [4]. Scholarly and policy literature has also stressed basic needs, reliability, affordability, adequacy, quality and increasing electricity consumption ([5–8]). If initial approaches tended to regard energy access as a singular occurrence – the provision of a 'modern' energy service to those without – more recently it is recognised that access is not a "single-step transition" but a "continuum of improvements" ([9]:2). Yet at which point on this continuum, and for whom, energy access is granted remains moot.

To address the definitional and implementationchallenges of working with the fuzzy and contested notion of energy access, the UN and World Bank have adopted a multi-tier energy access tracking framework. The framework captures the "multidimensional nature" of energy access ([10]:47) and outlines several attributes that it tracks through its multiple tiers. For electricity access, for example, these attributes are capacity, duration, reliability, quality, affordability, legality and safety [9]. For clean cooking, the criteria are health, convenience, safety, affordability, efficiency, quality and availability [9]. Yet despite the recognition of the multi-dimensional nature of energy access, it remains predominantly understood in technical terms, with a focus on an "increasing level of electricity consumption over time" at the household level [11,12]. While some approaches recognise the

* Corresponding author at: Technische Universiteit Eindhoven, School of Innovation Sciences, IPO 2.03, P.O. Box 513, 5600 MB, Eindhoven, The Netherlands.
E-mail address: a.kumar@tue.nl (A. Kumar).

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importance of taking into account issues of affordability, adequacy, reliability, quality and relevance for basic needs when assessing access [5–7,13], the predominant tendency, as encapsulated in the UN-World Bank Framework, is to assume that once energy services have been provided access is a relatively straightforward matter and that improved energy access can be built from the provision of such initial services.

Drawing on research conducted in South Asia, Sub-Saharan Africa and Latin America, this paper seeks to advance the understanding of energy access. First, we consider how the "needs" that energy should serve are conceived in relation to energy access and in turn how this *configures* the forms of service that are designed and implemented to provide access. Dominant approaches tend to work on the basis of a hierarchy of services, such that particular services (lighting, mobile phone charging) are regarded as basic needs whilst others (e.g. TV, kettles) are not. The UN-World Bank multitier framework operationalises this hierarchy of needs approach. Yet others suggest that "what matters ultimately to the end user is the utility of energy" ([14]: 16). Energy access should be mobilised in ways that accommodate people's agency of defining and deciding their (basic) needs [15] and measured not in terms of targets for the provision of certain forms of infrastructure but rather in terms of development gain that are locally specific and diverse [15,16]. Second, we examine what it means to move away from an idea of energy access as a singular momentum to a continuum, specifically focusing on the socio-technical dynamics through which access energy *endures.* We examine the value chains and social arenas within which energy access has to be sustained, and consider which forms of intervention may be the most successful in ensuring that gains in energy access can be sustained over time.

Over the past five years, small-scale solar energy systems have increasingly been heralded as a means upon which energy access as development can be built [17]. The falling cost of solar PV and the growing range and flexibility of solar innovations, from lanterns and home systems to micro-grids, has made solar an attractive technology in the quest to create access to 'modern' and sustainable energy [18,19]. In this paper we argue that the dominant framing of energy access in technical and economic terms creates specific configurations which mask the critical social and cultural dimensions that shape the extent to which solar can provide energy access, how such access is endured and its consequences for the kinds of energy transitions that are possible [20,21]. In examining these issues, we adopt an assemblage approach which suggests that access to such energy services is not only a matter of the material components of solar systems, but is configured by the social relations, regulations, standards, institutions, processes and practices that serve to make up a solar socio-technical assemblage [22–24]. Energy access is created not only through "designed and engineered material objects" but through an entanglement of "producers, infrastructures, users, consumers, regulators and other intermediaries" ([25]: 459; see also [26]: 900). Access to energy is therefore neither a singular endeavour nor a step-wise progression, but a condition sustained through the ongoing social, political and economic work of maintaining the provision of energy services [27–29]. In short, energy access is created by the socio-technical assemblage through which it is provided.

2. Taking an assemblage approach

The concept of assemblage is increasingly advanced across the social sciences as a means through which the complex and interwoven relations of and between the social and material can be interrogated. As [30]: 82) puts it is useful in, "decentring the technological artefact as the object of inquiry and expanding scholastic focus on 'technology' to include the vast social and cultural networks surrounding it". Mcfarlane and Anderson [31]: 162) have argued for the potential contribution of assemblage "not simply as a concept, but as an ethos of engagement attuned to the possibilities of socio-spatial formations to be otherwise within constraints and historical trajectories".

Although it is a conceptual approach that has to date had more limited purchase in relation to questions of energy access, Walker and Day's analysis of household energy vulnerability as assemblage is a notable example of what assemblage thinking can help unpack:

> "what might, through other kinds of lenses, be seen as coherent, similar kinds of force being in operation, can through assemblage analysis be revealed to be heterogeneous, quite diverse situations with internal inconsistencies and idiosyncrasies" ([32]: 23).

These insights provide a compelling argument for putting assemblage thinking to work in the context of energy access. The complexity and messiness of energy access as an empirical phenomenon produces a need for an analytical tool which is capable of grappling with the "inevitable gap between what is attempted and what is accomplished" ([33]: 1). The concept of assemblage allows the examination of "an array of heterogeneous actors", in "different spatial locations" and with "temporal rhythms" that more constrained theoretical approaches do not allow ([32]: 26). Energy services and how they can be accessed "cannot be understood in solely technological or social terms, but rather represent hybrid 'assemblages' operating across a multitude of scales and sites" ([34]: 34). Assemblages are 'open wholes' ([45]: 35), which are continually being assembled, disassembled and reassembled in time and space, generating particular agency. The notion of *agencement* as suggested by [35]:9) strengthens the point that assemblages are not simply socio-technical arrangements but "arrangements endowed with the capacity to act in different ways, depending on their configuration… agencies and arrangements are not separate". The capacity to act of a particular assemblage will, in other words, change if the socio-technical arrangement changes. For the endurance of energy access this is an important point: assemblages, are contingent and fragile configurations that require constant work [36].

While many researchers have documented the fluidity, indeterminacy and material agency of devices ([37]), the concept of assemblage offers a means of analysing how the fluidity and indeterminacy of devices are situated in time and space. By consistently attending to the agencies of both individual actors and the assemblage as a whole, where both entities and their agencies "can change over time and through interactions" ([38]: 25), assemblage thinking allows for registering "diversity of situations" and at the same time "reveals commonalities" of trajectories, influences, definitions and approaches ([32]: 26). For Ranganathan [39]: 1315), in case of stormwater drains in Bangaluru, India an assemblage approach "makes visible unusual suspects… disrupting how we conceive of agency and perform critique". Exposing the ways in which energy access is assembled helps critically reflect on it and address its inadequacies [40].

Critically, assemblage thinking draws attention to the operations of power. Working towards energy access inevitably disrupts established power relations long embedded in other infrastructural encounters and dis-encounters [41]. Power in the assemblage lies in all the agents, or rather, in their ability to mobilise different powers at different times. In a world that operates through combined human and material agencies [42], power "is recursively woven into the intricate dance that unites the social and the technical" ([43]: 18). This distributed notion of power opens up possibilities for examining how power operates through the push of multiple stakeholders, in multiple sites and through a range of diverse practices. Drawing on Li [36], the exercise of power in the assemblage involves reassembling, forging alignments, authorising knowledge, managing failures and contradictions and even masking political challenges as simply matters of technique. It also means acknowledging the materiality of infrastructure as a vibrant force [44,45]. Yet, there is a risk that such distributed understanding of power depoliticises the intentional or voluntary use of power by delegating agency to the assemblage as a whole[1]. Especially, gendered

[1] Thanks to the anonymous reviewers for reminding us of this point.

impacts of energy access projects result from not just an often advertent distribution of power within the assemblages but also pre-existing power distributions through social norms, biases and taboos [20,46]. Counterbalancing this, we highlight the need to be attentive to the specific workings of power in assembling particular solar assemblages and the distributions of agencies within them — through reference to specific decision making instances on a range of issues, from who and what is in need of energy, to how and by whom is the assemblage and its systems funded, managed and maintained.

In the remainder of the paper, we put the concept of assemblage to work to generate insights into the potential and limitations of solar for meeting the Sustainable Development Goal of providing energy access for all. Drawing on a series of studies on the use of small-scale solar in Bangladesh, Brazil, India, Mozambique, Sri Lanka and South Africa, we first examine the diverse ways in which access to energy services are configured through solar power before considering the extent to which such access can be endured. Through this analysis, we find three common features of solar energy access across our case-studies. First, there are significant gaps between what a solar project is designed for and what it delivers which are highly contingent on the flexibility of its structure and the decentralisation of agency within it. Second, access is often fleeting and needs considerable work to endure continuously. Third, in order to foster ongoing access to energy services, the design of solar projects would benefit from embedding logics of improvisation as a means through which energy access can endure. Our broader conclusion is that energy access is fluid and ever changing and we need fluid, easily maintainable, locally modifiable 'assemblages' for providing such access.

3. Methods

This paper brings together findings from six research projects carried out between 2010–2016 in Bangladesh, Brazil, India, Mozambique, South Africa and Sri Lanka. Raihana Ferdous did research in Bangladesh for her PhD theses at Durham University as part of an interdisciplinary research project funded by UK's Engineering and Physical Sciences Research Council (EPSRC) named 'Photovoltaics for Futures Societies'. Grant number: EP/I032541/1. Dr Britta Turner did research in Sri Lanka for her PhD theses at Durham University during 2011–2015. The thesis can be accessed free of cost here: http://etheses.dur.ac.uk/11550/. Dr Andrés Luque-Ayala conducted research in Brazil for his PhD research at Durham University during 2010–2014. The thesis can be accessed free of cost here: http://etheses.dur.ac.uk/10606/. Dr Ankit Kumar did research India for his PhD thesis at Durham University during 2011–2016. The thesis can be accessed free of cost here: http://etheses.dur.ac.uk/11387/. Prof Marcus Power and Prof Harriet Bulkeley led the Mozambique research as part of the UK's Economic and Social Research Council (ESRC) funded 'The Rising Powers, Clean Energy and the Low Carbon Transition in Southern Africa' project (http://community.dur.ac.uk/the.rising.powers/). Grant number: ES/J01270X/1. The project ran from 2012–2015. Prof Cheryl McEwan conducted research in South Africa as part of the EPSRC and Durham Energy Institute funded 'Sustainable solar energy for rural development in South Africa' project. Grant number: EP/K503368/1. South Africa interviews were carried out by the project Research Assistant, Dr David Bek, with the assistance of local field-worker Zaitun Rosenberg. All research projects used case studies to explore various aspects of the design and implementation of small-scale solar energy projects intended to provide access to energy services, including solar lanterns, home systems, hot water systems and micro-grids. Case study is one of the most common methods used in decentralised energy research [47], and although individual case studies provide essential insights, calls for further comparative case study research in this area have been made [48], which prompt a need to develop new comparative imaginations [49]. Bringing together findings from these projects has facilitated comparison and "cross-technology investigation" of solar ([50]: 2). Our case studies also bring together a range of actors together like banks, non-profit NGOs, for-profit companies, national governments, and bilateral and multilateral organisations.

All six projects collected data primarily using qualitative methods and adopted multi-methods approach including home tours, observations, interviews and group discussions which provide ideal tools to explore social and cultural dimensions [51,52]. While each research project was designed independently, they all sought to address the core question interrogated in this paper – why, how and for whom is energy access provided and configured, and how far has the access provided been endured over time, with what consequence? A series of workshops, bought the researchers together to explore commonalities and differences across the research they had conducted, leading to a common set of insights. As a result of these workshops central comparative themes were selected to enable a secondary analysis of the data in order to derive more general insights from across the different case studies.

In total, the paper draws data from 482 interviews, 91 home tours and 12 group discussions. The case-studies, field sites, dates and duration of the fieldwork undertaken and the specific methods deployed are detailed in Table 1.

4. Configuring solar energy access

This section illustrates that what is considered as 'need' often shapes the socio-technical configurations of solar systems. Across our case studies, we see that solar systems are variously designed and delivered to target particular needs. In some case studies, the 'hierarchy of needs' captured by the UN-WB framework was apparent. For example, solar home systems in Bangladesh, Sri Lanka and a range of energy interventions in Mozambique either targeted lighting and mobile phone charging (Tier 1), or could be modified to power fans or TVs (Tier 2) (Fig. 1). Yet in others there was a more open disposition to what constituted demand for energy services and how this might be met.

Defining 'needs' is one of the main ways in which power within the energy assemblage is exercised, revealing that where 'needs' are closely defined, the resulting solar assemblage is orientated towards their provision. For example, Lighting a Billion Lives (LaBL) solar lanterns prioritise lighting needs for education and commercial activities. This not only limits electricity access to only lights but also the lights provided by solar lanterns are predominantly limited to male members of village society whose educational needs are prioritised above women's uses of light for domestic tasks [20]. Women in villages with solar lanterns fail to gain access to this modern energy service, and must remain content with kerosene lanterns.

Our study reveals that, contrary to normative understanding, fixed/flexible and centralisation/decentralisation are not just matters between centralised national grids and decentralised off-grid projects. Off-grid projects themselves fall on a spectrum of fixed/flexible and centralisation/decentralisation. Through our case studies we find that various socio-technical configurations of solar are more/less fixed or flexible, on a continuum, allowing for needs to shift and be reinterpreted or not. Fixed, uniformly configured interventions like solar lanterns serve to limit energy access to particular kinds of service. Such systems often fail to account for varying needs, desires and capacities such that they end up providing very specific kinds of energy access for particular social groups. The flexibility of the socio-technical configurations of systems like solar home systems enables them to be directed to different kinds of energy service, like watching television or charging batteries for other uses (see [54] on users in socio-technical systems). They can be tailored to various uses. This creates 'more' access, in as far as the energy provision enables increasingly diverse forms of service. These energy assemblages remain open to configurations other than those imagined by the designers.

Although some energy assemblages are more closed than others, they do not remain completely fixed. They are open to contestations.

Table 1
Case Studies & Research Methods.

Country	Case-study	Field Site	Date & Duration	Stakeholder interview (funding agencies, government officials and sectoral experts)	Provider Interviews	User Interviews	Home tours	Group discussions
Bangladesh	Solar home systems (SHSs) provided by Infrastructure Development Company Limited (IDCOL), a state-owned non-banking financial institution that works to reduce the financing gap for developing medium to large-scale infrastructure and renewable energy projects in Bangladesh. IDCOL's SHS programme has been working since 2003 as part of the government's Vision 2021 – Electricity for All. It has a target to finance 6 million SHSs with an estimated generation capacity of 220 MW of electricity by 2021. Initially the World Bank and Global Environment Facility supported the programme. After meeting considerable success several bilateral and multilateral organisations (GIZ, KfW, ADB, IDB, GPOBA, JICA, USAID and DFID) also joined.	Sandwip Island, along the southeastern coast of Bangladesh in Chittagong District. The island is 50 kilometres long and 5-15 kilometres wide and has a population of about 350,000.	2012-2014 10 Months	10	13	26		
Brazil	3 cases were considered. First, the use of solar hot water in social housing in São Paulo, promoted by Sao Paulo's Social Housing Agency (CDHU). Second, the process of development, promotion and implementation of a do-it-yourself (DIY) low-cost solar hot water (SWH) systems aimed at low-income population in São Paulo carried out by the non-profit Society of the Sun. Third, São Paulo's Solar Cities initiative, a joint initiative between the NGO Vitae Civilis and the Brazilian Association of Manufacturers of Solar Hot Water Systems (DASOL) aimed at lobbying local authorities for the adoption of local bylaws requiring or facilitating SHW use.	São Paulo, Brazil	2010-11 6 months	17	21	14	6	
India	Lighting a Billion Lives (LaBL), a solar lantern programme[a] aiming to provide solar lighting to a billion people around the globe. It sets up solar charging stations with 50-60 solar lanterns. Entrepreneurs manage charging stations and rent lanterns to villagers. The projects are funded by corporate social responsibility, government and bilateral and multilateral organisations. LaBL has been successful in setting up projects in 2222 villages in India, affecting more than 100,000 households [53].	Bihar state of India. Bihar has the lowest percentage of people with access to electricity among the Indian states.	2011-12 9 months		8	67	55	9
Mozambique	Solar PV projects in rural spaces established by Fundo de Energia (FUNAE), the state agency charged with rural electrification with donor funding. These included: (1) solar PV projects financed by the Indian government at the Têngua boarding school and health centre and at the Paquete primary school (both in Milange District, Zambézia province); (2) a solar mini-grid system funded by the Belgian government which was installed at Villa Chinhambudzi in Manica province and (3) a World Bank-funded project to provide distributed solar streetlights, and electrify the administrative post, school and clinic at Mavonde in Manica province.	Milange District, Zambézia province Villa Chinhambudzi in Manica province Mavonde in Manica province	8 months	13	9	201		3

(continued on next page)

Table 1 (*continued*)

Country	Case-study	Field Site	Date & Duration	Stakeholder interview (funding agencies, government officials and sectoral experts)	Provider Interviews	User Interviews	Home tours	Group discussions
Sri Lanka	Solar Home Systems (SHS) purchased as part of the Renewable Energy for Rural Economic Development (RERED) project: a market-based World Bank (WB) and Global Environment Facility (GEF) funded project which lasted from 2003 -2011. During the RERED project, and the previous Energy Services Delivery (ESD) project that ran from 1997 – 2002, a total of 131,528 SHSs were installed in Sri Lanka. Rural un-electrified households throughout the country, predominantly facilitated by micro-finance arrangements, purchased these.	Rural villages in the North-western, Central and Uva provinces	2012 6 months	10	5	30	30	
South Africa	Boomplaas informal settlement was the chosen location for the implementation of a household level solar PV project during 2012, costing R1 million. Each of the 16 households is connected to a small 'power station' containing two 240 W solar panels, a 1000 W inverter and six 2 V batteries. Each household also received internal wiring, including the fitting of pull switch lights and plug sockets for attaching appropriate appliances. The project was conceptualised and delivered with backing from senior provincial politicians, but capacity is below expectation, no mechanisms were put in place to provide on-going maintenance and support, and several units have failed. Second, Chargo Trust farm complex has invested successfully in solar water heaters for its worker houses. In 2011 a decision was taken to install 110 low-pressure geysers on the housing units in order to reduce electricity costs. A subsidy from the energy parastatal, Eskom, provided approximately 75% of the project cost, with each geyser and full installation costing R4400. The system heats water used for washing, cooking and making hot drinks, and electricity consumption has been substantially reduced generating savings for both the farm workers and the Trust.	Boomplaas informal settlement near Keimoes, Northern Cape Chargo Trust farm complex, near Kakamas, Northern Cape	2012-14	11	6	21	21	
Total				61	62	359	112	12

[a] LaBL also uses micro-grids and solar home systems but this paper is limited to its solar lantern work.

Multi-tier Matrix for Access to Household Electricity Services

	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Tier criteria	Not applicable	Task lighting Phone charging	General lighting Television Fan (if needed)	Tier 2 AND Any medium-power appliances	Tier 3 AND Any high-power appliances	Tier 4 AND Any very high-power appliances

Fig. 1. UN-WB multi-tier framework [9].

Our research also shows how users create flexibility within fixity highlighting how human and material agencies combine in creating access as defined by those who need it. Users 'hack' systems in order to enable them to access the kinds of service that they require. Although fans are not allowed in most IDCOL solar home systems in Bangladesh, many users secretly extend connections to use fans. The degree of flexibility or fixity in any given socio-technical assemblage and the forms of energy access it provides is therefore not only a matter of the opening up or closing of the technical design of the system and its economy, but of the everyday practices of energy use and the social and cultural contexts in which this takes place. However, the opening up of designs of these energy assemblages affords greater flexibility of use to a greater number of people.

What we see then is that solar assemblages can entail flexibility from the outset, where both the needs to which they should be directed and the nature of their configuration are open to user-participation (more, or less intentionally) in their design, implementation and upkeep. For example, solar home systems in Bangladesh and Sri Lanka, although fixed to an extent in their configurations turn out to be more flexible than solar lanterns. As loose assemblages of panels, batteries and wires, these solar home systems are open to user interventions in adding panels, batteries, light connections, and fans and TVs.

The capacity to shape the flexibility/fixity of any particular solar configuration is related to the nature and distribution of agency within any particular assemblage, which serves to delimit the kind of energy access provided, how access is achieved, for whom and how access is endured (see also [55]). Across our case studies, we can see a continuum from centralised to distributed forms of agency. Centralised agency exists in projects that are predominantly designed and deployed 'top-down', primarily through donor-driven agendas which tend to focus on 'globally accepted' energy services for 'basic needs', primarily lighting and mobile phone charging. Where agency for determining the nature of access is distributed through either participation in design of schemes or through market-based schemes, energy service provision is more diverse, including entertainment and refrigeration alongside basic needs for lighting.

It is important to acknowledge that 'hacking' is not equally distributed across all social groups. We find that a more flexible configuration and its benefits are exploited most by those who have the capacity (financial, knowledge) to exploit its flexibility, i.e. power in the energy assemblage is unequally distributed. As McFarlane [56]: 665) explains, assemblages can be "captured, structured, and storied more effectively and with greater influence by particular actors or processes than by others". For example, in Sri Lanka, the extent of access depends on people's capacity to either enter the market to supplement basic solar home systems, or to 'hack' the solar home systems that are meant to provide lighting to instead watch television. Using their own capacities, they modify or extend their energy access. Therefore, the distribution of agency in the assemblage is not independent of the agency of particular social groups.

4.1. Configuration of, and agency in, the case studies

In Bangladesh, until May 2017, IDCOL's solar home system (SHS) programme installed about 4.12 million SHSs in areas where electrification through grid expansion is challenging and costly. It covers 18 million people, i.e. 12% of the country's total population, and targets an estimated generation capacity of 220 MW of electricity to support the government's vision Electricity for all by 2021. IDCOL is responsible for the overall project management and defines the technical standards of equipment. IDCOL also secures grants and soft term credits from multiple donor organisations and provides grants and loans to partner organisations (PO/NGO). POs buy SHS equipment and spares from the IDCOL's approved suppliers, extend loans to customers, and sell SHSs, as well as provide maintenance services and standardised spare parts during the credit period. Once the credit period is over, customers can pay yearly fees to POs for maintenance. The socio-technical configuration of SHS in Bangladesh are somewhat flexible as the services from various systems can range from only lighting and phone charging to powering television sets. Although the system configurations are designed and defined by IDCOL, users often covertly or overtly tailor them according to their needs. This puts the agency in them between centralised and decentralised.

We consider the socio-technical configuration of the solar water heating (SHW) systems in Brazil as also flexible, as they offer the possibility of having a range of system sizes and access modes while also enhancing flexibility within the national electricity grid. Agency in SHW follows a combination of decentralised and centralised logics, given the standard configurations of systems (a form of centralization using nationally approved standards) alongside the possibility of SHW DIY systems where users are in control of design and management decisions around their energy provision. Yet, even in its most decentralised configuration, this arrangement of solar energy does not escape the logics and drivers of the fully centralised electricity grid. The active promotion of solar hot water in Brazilian cities is largely the result of existing constraints in the national grid—a way of responding to the widespread use of electric showers and its unmanageable peak demands. With electric showers responsible for 6% of the total electricity consumption of the country and 18% of the peak demand, alternative mechanisms for the provision of energy for the purpose of water heating is a national priority. SHW systems here, promoted by government agencies in the context of social housing, are envisioned not simply as a matter of energy access but also as a solution for national-scale energy problems.

The LaBL solar lantern programme in India has standard configurations of charging stations with standard number of lanterns. The lanterns have fixed capacities often providing only lights (in some cases mobile charging). LaBL's socio-technical configuration is fixed. The programme team at the top decides the solar lantern capacities. Specific technology partners provide solar lanterns, perform major maintenance activities and provide spare parts. A local NGO is the implementation partner and can perform minor maintenance activities but only with spare parts from technology partners. The users do not have a say in the configuration of the lanterns or the charging stations and cannot modify the lanterns for other electricity services. The power relations are skewed towards the project managers making the agency within LaBL centralised. The solar lantern programme developed in a situation of lack of state's central grid electricity access and aimed to move people away from kerosene lamps. It also received funding from government agencies like the Ministry of New and Renewable Energy to provide a solution until the national grid arrived.

FUNAE in Mozambique is involved in various types of solar projects. However, these projects are of standard configurations. Therefore, we categorise its socio-technical configuration between fixed and flexible. FUNAE funds, designs and develops all projects in a top down manner with limited and often superficial user consultations. FUNAE also controls the supply of spare parts and maintenance services. Users have no opportunity to modify and adapt projects. Local participation in shaping electrification, whether on-grid or off-grid typically consists a consultation with, or consent from, non-state actors, rather than people proactively shaping projects [57]. A central aim of FUNAE projects is the extension of state and its powers, and making the presence of a centralised state felt in decentralised areas. We categorised the agency within FUNAE projects as centralised.

Both projects in South Africa were parachuted into the communities with their standard configurations with minimum opportunities of interventions by the users. Their socio-technical configurations are fixed and the agency within them is centralised. For example, the Provincial Department of Agriculture, Land Reform and Rural Development designed and financed the Boomplaas project upon insistence by a senior member of South African Communist Party (SACP), a part of the ruling alliance, who attended a meeting at Boomplaas during 2011, noted the lack of electricity and demanded action. There was some form of consultation with the community and electricity emerged as a major priority. However, political figures, lacking technical expertise, made promises about the system's capabilities that were unrealistic. In addition, no formal ongoing management programme was costed into the project. Two members of the community received a week's paid training whilst the system was being installed to ensure the local provision of at least basic maintenance services. However, neither received any payment to provide maintenance service, yet were constantly asked by community members to check and fix their systems. A marginal community has thus been left to organise maintenance for themselves, with very limited knowledge of the technical aspects of the system's maintenance and a lack of capital to pay for ongoing maintenance and repairs. There is some promise of repairs by the system installers, but if there is evidence of negligence or interference by householders in the workings of the system then the installers will not take the responsibility of free repairs or upgrades. Thus, people are left with a liability rather than an asset.

In Sri Lanka, the power to determine system standards and overall implementation framework lay centrally with DFCC Bank Development Finance Institution. However, they had limited success in enforcing these when system installers made other choices in order to maximise their financial gains. The model favoured installers who also received support in setting up business. Microfinance institutions supporting the users made full payments for systems to the installer, which meant that when systems malfunctioned the installer had no incentive to fix them. Their income did not depend on services after installation. The possibility of selecting from two system sizes puts the socio-technical configuration of solar home systems in Sri Lanka as somewhat flexible. The agency within them has come to be between decentralised and centralised not because it was intended to be so but because the system funders and installers did not assume the responsibility for spare parts and repair services. The standard configurations of systems were pre decided and individual customers had very little power / voice in relation to the other sets of actors. On the flip side, they were left alone to tinker and some were able to derive to a range (albeit limited) of services depending on how they managed their own systems.

Taken together, our analysis of multiple small-scale solar projects demonstrates that the diverse ways in which energy access is being provided is a function of the flexibility/fixity of the socio-technical assemblage and the de/centralisation of agency (Fig. 2). We find that centralised schemes tend to be more fixed in their design, providing a more limited range of energy services, whilst those where agency is dispersed can be more flexible in terms of the services that solar can provide. While the first has a closed conceptualisation of 'needs', the second is more open about what 'needs' might mean for different groups, and which 'needs' they might want to operationalise. Yet, while solar assemblages are relatively stable, we witness for example the uneven provision of access as particular groups are 'designed out' of specific schemes, attempts to 'hack' systems, or requirements for additional social/economic resources to gain access to the 'higher order' services that solar power has to offer. This is not a matter of a simple hierarchy of energy needs or a stepwise progression, but of an ongoing contested process of struggling over access to energy.

5. Enduring solar energy access

Rather than being a singular intervention, our analysis shows how energy access is a constant achievement, a precarious outcome of the agency deployed through ongoing work to configure energy provision. The endurance of energy access is therefore far from secure [58] and always has the potential to become undone. Across our case-studies, we find three key factors that lead to the 'undoing' of energy access: (a) the ways in which solar is initially taken up within the complex web of energy services; (b) the temporalities of solar power and its temporary nature; and (c) the extent to which projects design in the capacities to ensure that energy access endures.

5.1. Fitting solar energy in

Despite its promise of delivering access to 'modern' energy services, across our case studies we find that solar energy has difficulty fitting into the practices of everyday energy use. First, small-scale solar is often designed, as discussed above, to offer specific services and limited amounts of power. Where systems are limited, either by the configuration, devices or batteries deployed, solar energy provides for only some of the services upon which people depend. In short, access to solar energy does not *replace* existing traditional energy use, but operates somewhat intermittently alongside these alternative forms (see also [59] on fuel stacking). In India, Sri Lanka, Bangladesh and Mozambique we observe that solar is invariably complemented by other energy sources and services, like kerosene oil. Furthermore, solar commonly provides only electricity or hot water. For cooking and heating services, which have specific gendered impacts [20,46], people depend on wood or charcoal. Where solar energy has seen widespread take up, for example as a form of hot water heating in South Africa or Brazil, this is because it provides a specific service alongside other forms of energy provision [27,60]. Solar is often rather awkwardly positioned in relation to these other forms of energy provision, seen by many participants in our case-study research as inflexible and difficult to budget for compared to alternative sources that can be consumed in smaller units on a 'pay as you go[2]' basis, like litres of kerosene or bundles of wood. This gives people flexibility of using more or less energy on particular days and saving for the future. In solar projects like LaBL, people pay fixed rental for solar lanterns, irrespective of the quantity of energy they use. With kerosene people can also distribute smaller amounts in several lamps and light multiple spaces. In contrast, one solar lantern can light only one space at a time. The inflexibility of solar electricity is lessened in micro-grids and solar home systems, though here the additional costs of enabling solar to occupy different spaces and times – multiple bulbs, holders and wires – is an impediment compared to the ready divisibility of traditional energy sources. Enduring access to solar energy therefore requires that its services are sufficiently desirable that the additional, and different, forms of finance and use it requires are endured in the face of the ongoing availability of traditional alternatives.

5.2. Temporalities and temporariness

Energy provision and use contain their own and often distinct temporalities [61–,62,63]. In the case of solar, while the availability of daylight drives its primary provision, the use of batteries or other forms

[2] More recently solar projects have adopted smart metering technologies to enable pay-as-you-go systems but none of our case studies use such systems.

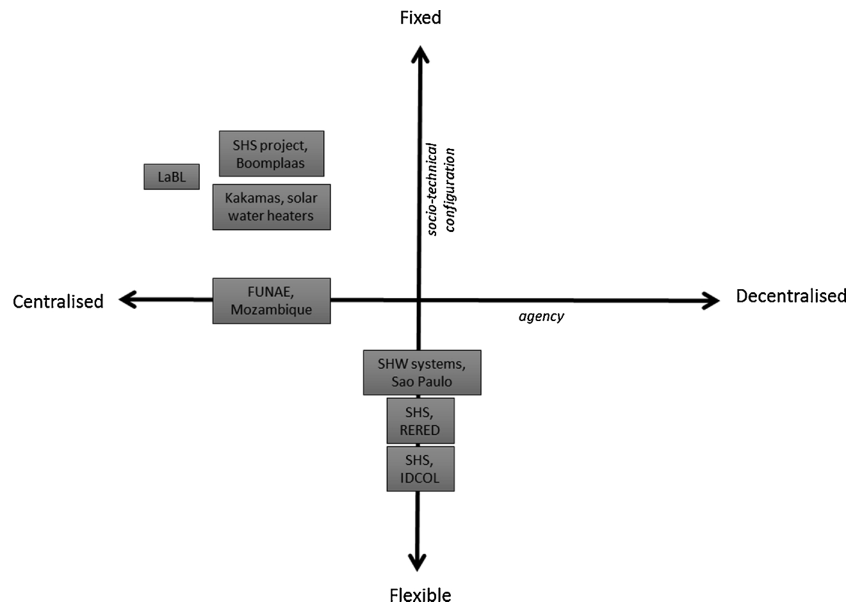

Fig. 2. Socio-technical configurations of access.

of storage may also consequently determine its availability. In São Paulo, solar hot water systems work by providing an energy service – hot water – at both the beginning and the end of the working day, when it is commonplace to shower. The temporality of solar energy here is not simply related to the times of use, but most importantly, since solar hot water is seen as an alternative to electric showers, to the temporalities of the national grid and peak electricity demand [27]. In our other case-studies, the primary form of power storage was the battery – an obligatory passage point in the working of the solar assemblage [64]. Obligatory passage points are the essential nodes that may enable or disable the functioning of these energy assemblages. Small-scale solar batteries enable energy produced during the day to be used for services such as lighting, entertainment and cooking during the evening hours. The care and maintenance of batteries, frequently borrowed for this purpose from other socio-technical assemblages such as cars, is then critical to the ongoing use of solar power [29]. During winter or the rainy season where daylight and hence power is less abundant, certain services (such as TV and stereo) become unavailable while light, for which there is greater demand, is less readily available. This intermittency serves to reinforce dependence on traditional energy sources, despite their limitations.

The awkward temporalities of solar exceed daily or annual cycles. As a form of energy, we found solar to be primarily regarded as a temporary, in-between condition. In India, Bangladesh and Sri Lanka our research found that the framing of solar as a temporary solution was a critical and performative part of its narrative. Many people never expect it to last, but rather see it as a form of 'pre-electricity', a stepping stone to grid electrification [65,66]. If solar power is seen to be a temporary affordance, it is not surprising that it is indeed performed as temporary. Evidences from India, Sri Lanka and Bangladesh suggest that everyday practices which serve to reduce the longevity of solar systems, such as draining battery power, and which are often regarded as a consequence of a lack of education or technical knowledge, are in fact driven by this understanding of solar as a temporary solution. People deliberately drain the battery capacities of solar home systems and lanterns to maximise benefits of their investments or the rental payments in the short run, despite knowing that this jeopardises the longevity of the system, because they do not expect to be using solar power in the long term. This in turn serves to diminish the capacities of solar provision, leading to the 'failure' of energy access and frequently returning people to a reliance on traditional energy sources while they wait for 'grid' power to arrive [28].

Grid power, its promise or its arrival, serves to further 'undo' solar energy access. The mismatch between the DC power of solar and the AC electricity of the grid make their combined use highly problematic. In some households in Sri Lanka and India, AC-powered devices such as rice cookers, electric kettles and DVD players are assembled and lie idle waiting for the grid to arrive, further attesting to the limitations of solar power (Fig. 3). Elsewhere, the arrival of the grid requires households to invest in new equipment, such that even though the continued use of solar power during daylight hours or as back-up during power cuts might be desirable for most it is not practical to have two sets of devices available for use. This finding points again to the limited value in regarding energy access as a 'step wise' progression through different levels or forms of electricity provision, and instead suggests that each new configuration of energy service provision brings with it new kinds of (uneven) access to energy service, potentially undoing or reducing services for some while bringing additional services to others.

5.3. From maintaining technologies to enduring energy access

Across all of our case studies, we find evidence of 'drop and go' interventions where project designers fail to secure the capacity to maintain solar energy provision once they have been established. In India, Sri Lanka, South Africa and Mozambique, our research found that solar projects can suffer from a lack of timely monitoring, maintenance, servicing and spare parts which serves to build in the 'failure' of solar provision from the outset. For example, according to the LaBL manager interviewed during fieldwork, spare parts and maintenance staff often arrived only when a number of breakdowns accumulated and economies of scale took effect. This meant that many lanterns were in various stages of disrepair for weeks or months. Where these issues are addressed, for example in the case of a solar hot water scheme in South Africa, where investment to ensure the on-going maintenance of geysers was made up front, service provision has been maintained.

Elsewhere, users develop the capacity to improve solar provision through various forms of improvisation – as suggested above, 'fixed' systems are often 'hacked' to creative purposes with solar lanterns used to charge mobile phones, or home systems meant for lighting used for TV. In South Africa, Northern Cape farmers have added extra panels to home solar systems to enhance capacity, but often without technical knowledge and using mismatched components that actually reduce

Fig. 3. A television and DVD player stored safely, waiting for the grid to arrive (Photo: Ankit Kumar).

capacity. Opening up solar provision to such improvisation might be one way of ensuring their ongoing access, for "improvisation allows the work of maintenance and repair to go on", even if the technology changes from its original form ([23]: 4). Enabling users to put solar to work on their own terms appears from across our case-studies to be one critical means through which energy access endures

While maintenance of technology is important, we argue that the discussion needs to move to an idea of endurance. Maintenance, as normatively understood, focuses on the technologies, while putting the fluid nature of energy access out of focus. We need to put the fluid nature of energy access centrally and decentre the idea of maintenance of the technologies in the forms that they are initially set up. The idea of endurance provides a better entry point into this. We argue that energy access endures through adaptability, flexibility and improvisation of technology rather than attempting to maintain the technology itself in its initial form.

6. Conclusions and way forward

In summary, we make four recommendations for furthering the scholarly and practice work on energy access. First, we argue for the uptake of an assemblage perspective. Being attuned to how particular socio-technical configurations of energy access are continually being assembled, disassembled and reassembled in time and space and how this impacts their agencement will enable policy makers and practitioners to design projects that are more robust and better able to endure because they are not expected to do so without continual effort. Drawing inspiration from an assemblage perspective, energy access projects and devices should be understood as "open wholes" ([45]:35) where the actors, material components and constituents of the project may change over time and so may the effects of these projects. Endurance of energy access provision then comes not from preventing the socio-technical assemblage from changing, but from developing capacities to respond when it does.

For social scientists of energy, in addition to the above points, an assemblage perspective lends focus to a diversity of actors in different spatial dimensions and temporal rhythms that more constrained theoretical approaches do not allow. This makes an assemblage approach useful for enquiring about the historically embedded social and cultural issues that operate in the everyday lives of users of energy and that mediate their participation in solar assemblages.

Second, our analysis suggests that central to energy access is the flexibility/fixity of energy assemblages and centralisation/decentralisation of agency and power within them. This determines what and for whom solar is designed and what it can deliver, i.e. what definitions of access are mobilised and what ideas of needs are embedded. Power is not equally distributed across the assemblage; rather, it is uneven, with particular stakeholders deciding what is 'in need', other stakeholders guarding the power of establishing product configurations or maintenance regimes, and finally others exercising their power and resistance through small scale 'hacks' that customise systems to their needs. As we explain, flexible energy assemblages afford a greater access to energy services which people are able to extend further when they have the required technological, economic and knowledge resources. A decentralised agency lets actors determine the energy services they need and the extent of access they require.

Third, scholars and practitioners should not regard access as something that can be 'achieved'. It needs to endure. Here we urge a focus on three key dynamics – how solar fits into the energy assemblage of the households, the temporalities and temporariness of solar and the need for thinking about providing energy access that endures rather than just maintaining specific forms of technologies. These attest to the fact that energy access is a 'precarious accomplishment' requiring ongoing hard work to "sustain connections in the face of tension" ([36]: 264). Therefore, it is also worth adding endurance to the UN and World Bank multi-tier energy access tracking framework that already includes capacity, duration, reliability, quality, affordability, legality, and health and safety.

Fourth, to ensure energy access endures, projects should embed logics of improvisation, share technological information with users and open up the field of maintenance. This will facilitate endurance of access rather than just maintenance of technologies. Endurance goes beyond simple maintenance. It embeds the idea that the breakdown of a technology will not lead to the breakdown of access. Activities like improvisation will bring the technology back to life so that access to energy continues, with effects that people desire from it. These will result in networks or hybrid projects accumulating project designers' imaginations and users' improvisations ([23]: 4). Through this, energy access, even if in changing modes, could endure for longer periods. By enduring for a longer period, the perception of reliability of solar as a longer-term solution could also strengthen.

Our broader observation is that energy access is fluid and ever changing. This is because the idea of access itself moves as people gain more or less electrical devices, go through different periods of life, get involved in different forms of economic activities, and so on, but also the modes of providing access break down, work at reduced capacity, change their properties and so on. We need fluid, easily maintainable, locally modifiable 'assemblages' for providing such access. As de Laet and Mol [37]: 253) so succinctly explain in the case of the Zimbabwe bush pump, fluidity is particularly useful for "technologies transferred to, or designed for, so-called intractable places". Fixity/flexibility of the socio-technical design and centralisation/decentralisation of the agency thus matter. Flexibility and decentralisation make solar assemblages more fluid, more open and more capable of providing energy access that endures.

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